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APPENDIX NO. 12, 1897.

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REPORT ON THE MEASUREMENT OF THE SALT LAKE BASE LINE, IN UTAH.

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By WILLIAM EIMBECK, Assistant.

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The question of the location of a primary base of verification within the thirty-ninth parallel triangulation in Utah had received much attention in connection with the development and execution of that triangulation through eastern Nevada and Utah. The extent and scope of the geometric figures of this triangulation are exceptional and without a precedent in practical geodesy.

Measured along the central parallel, for example, the main chain lying between the Yolo and El Paso base lines is approximately 1,680 kilometres in extent, and is composed of but eight distinct trigonometric figures, containing not less than 10 lines of 230 kilometres average length. The longest one of these, stretching eastwardly from "Ellen Peak" across the delta of the Green River to "Uncompahgre Peak," is nearly 300 kilometres in extent. As regards heights, the triangulation is no less remarkable. Traversing the mountains at an average elevation of about 11 000 feet, it culminates, on crossing the Continental Divide, in central Colorado, at an elevation of 14 300 feet above the sea.

Though executed in every phase or feature with the utmost care and the very best of instrumental appliances, yet, on account of its unprecedented scale and the consequent problematical character of its final results, the measurement of a fundamental base near its middle meridian was deemed desirable, and, indeed, necessary, and was therefore decided upon as far back as 1883.

For the location of such a base the broad and open valleys of central Utah afforded special advantages. Their easy accessibility and their settled condition or state of cultural development adapted them most admirably for the measurement.

Accordingly, with that object in view, the preliminary examination of these valleys was begun in 1884 in the vicinity of Mount Nebo. It was thence carried into the Juab and Sanpete valleys and the open plains about Oasis and Deseret. Later on, in 1887 and 1888, the reconnaissance was extended into the basin of Utah Lake, and thence northward to the valley of the Jordan River and Great Salt Lake. The immediate outcome of this exhaustive reconnaissance was the discovery of many highly favorable base-line sites, notably those situated in the Juab, Sanpete, and Salt Lake valleys. A few of these sites, though favorable for measurement, had to be abandoned on account of the inelegance and inadequacy of the expansions of the trigonometric nets necessary to connect them with the main scheme.

But the verification and support of the linear element of the thirty-ninth parallel triangulation was not the only object it was sought to accomplish through the *location* of this base. The connection of the astronomical longitudes at Salt Lake and Ogden cities was also to be considered. These two important astronomical stations, which had served also as principal points of departure in the geographical exploration surveys within the mountains of the West, required intimate connection with the main work of the parallel.

Again, the height of the base above the level of the ocean was another question of moment, which claimed consideration. In a geodetic work of the precision and general refinement of the Rocky Mountain and Nevada sections of the transcontinental arc, it seemed manifestly inexpedient to depend for the elevation of one of its fundamental bases upon the trigonometrically determined

heights without verification by reliable spirit levels, especially in view of the circumstance that the heights of the Utah stations, largely derived from lines of uncommon length, were brought over a thousand kilometres from the ocean. In view of this it was obviously much to be questioned whether the heights could be regarded as possessed of that degree of precision deemed needful for the reduction of the proposed Salt Lake base. On the other hand, the transcontinental levels of the Union and Central Pacific, and other railways centering at Ogden, brought over from the seas, were the only lines of spirit levels at present available. The connection of the base site by spirit levels with the elevation of the railway crossing at Ogden was, therefore, regarded as necessary.

In consideration of the above and the desirability also of an extension of the triangulation in Utah along the 112th meridian, as a link essential to a comprehensive trigonometric survey of the United States,\* the main chain was subsequently expanded over the basin of the Great Salt Lake by a single quadrilateral. This elegant figure hinging upon the line "Nebo-Ibepah" is the largest quadrilateral in the whole work, and covers an area of nearly 10 300 square miles. The central station "Deseret" was introduced in order to facilitate the geodetic connection of the astronomical stations referred to, as well as the base line situated between Ogden and Salt Lake City. For the convenient and effective connection of these latter points, and particularly for the extension of the triangulation to the northward into Idaho, this quadrilateral figure will prove of much value.

Upon thorough consideration of the merits and demerits of the several sites from time to time reported, it was finally decided, in view of the reasons above set forth, to adopt and measure the base line situated upon the shores of the lake, near Hooper, unquestionably the most eligible and satisfactory site found that seemed well suited for economical connection and measurement, notwithstanding the fact that its connecting net extends in large part over the waters of Great Salt Lake. For illustration of the base net see pl. 1.

*General location.*—As will be seen from the accompanying triangulation sketches, the base line is situated upon the flat lands extending along the eastern shore of the Great Salt Lake, from the mouth of the Weber River to Farmington. Its northern end is located upon the grounds of Mr. Cato Love, at South Hooper, and its southern end opposite Kaysville, within school section 16, township 3 north, range 2 west of the Salt Lake principal meridian of the Utah land surveys. The approximate length of this base is 11.2 kilometres. The site is smooth and nearly level, excepting a slight swell near its middle at Beard's Point. The principal constituent of the soil is sand intermixed with loam. The southern half is alkaline, and being covered in part with a salt grass, and sage brush is used for pasturage purposes throughout the year. The three northern kilometres of the line pass through well irrigated, cultivated fields.

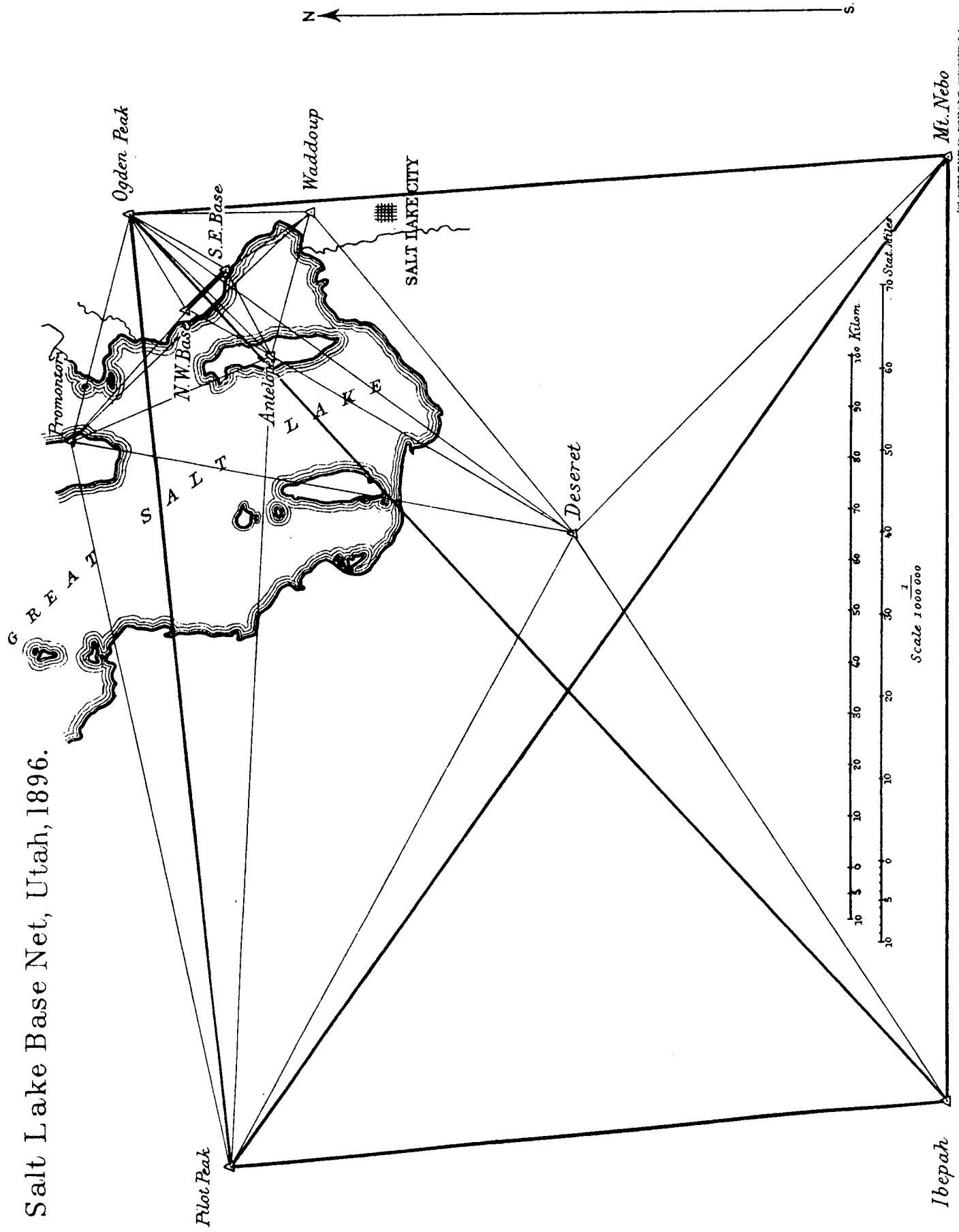
During the dry season (summer and fall) the ground is hard and admirably adapted for base-line measurement with apparatus supported by trestles. There are some farm improvements at various points along the site, but a slight change in location resulted in clearing it of every consequential obstruction, excepting at the stackyard of Mr. Beard, where a couple of grain stacks had to be removed to make passageway for the shelter-sled. Among the minor obstructions which could not be avoided may be mentioned twenty-eight barbed-wire fences, a railroad embankment, a turnpike embankment, some deep furrows, and numerous water ditches. The two largest of the latter had to be bridged over. Each of the twenty-eight wire fences had to be taken down and replaced once in each measurement.

Though the provisional location and trace of this site had been made and decided upon before I entered upon the occupation of "Waddoup" and "Antelope" triangulation stations, to Assistant J. J. Gilbert is due the credit for final location. Under my direction Assistant Gilbert prepared the site for measurement, perpetuated its terminals by substantial stone and brick monuments, and executed a complete topographical survey.

The brick piers at south and north base—that is, the permanent surface monuments which mark the position of the base—were built with the view to serve also as pedestals for the 20 inch theodolite used in observing the triangulation net. These piers were carried to a height of 9 feet in order to lift the instrument above the stratum of superheated and boiling atmosphere, a condition that seemed to prevail over the barren flat lands of the Salt Lake Valley at nearly all hours on sunny days.

\* See Proceedings of Geodetic Conference, App. No. 9, Report 1893, p. 360. Report, Committee on the Measurement of Arcs.

# Salt Lake Base Net, Utah, 1896.



The base, divided into eleven sections, was accurately traced by stakes set firmly in the ground. At every kilometre from south base a prismoidal stone 20 inches in length was firmly planted by packing the ground solidly around it. In the centers of these stones, dressed down to 5 by 5 inches square, were inserted  $\frac{5}{8}$ -inch copper bolts secured in place by sulphur. Fine cross lines (+) cut normal to the direction of the base defined the exact section points.

Half-kilometre posts were subsequently provided for the exclusive purpose, as will appear farther on, of subjecting the Duplex to a thorough test with respect to its behavior as a thermically perfect field measure. These posts consist of 4 by 4 Oregon fir 20 inches in length firmly planted in the ground. Ordinary 2-inch wood screws, with notch set normal to the base, mark the exact division points. The faces of all these posts and stones were placed accurately level, and flush with the ground. Heavy pencil lines drawn across the tops of these posts and kilometre stones in the line of the base served to accurately flag out the base in advance of the measurement, and to orient the centimetre scales for the "set-up" and "set-back" measures. The base was ranged out by 2 by 2 inch flag poles 7 and 10 feet in length, marked at their tops by a black and white band, set true to line, and secured in a vertical position by appropriate bracing. The shorter 7-foot flags were set up at the half-kilometre posts and the projecting 10-foot flags at the kilometre stones. The "range" thus established afforded a convenient means of controlling the direction of the measure without the aid of *adjusted* aligning telescopes. No grading of the line whatever was required. Although slightly rough in places, the clearing away of sage and grease brush and of some sunflowers was all that was needed to put the site in condition for measurement. Some little plowing and ditching was also necessary in order to drain off pools of water that had accumulated in places from flowing wells or overflowing irrigation ditches.

The convexity in the profile of the base necessitated the erection of 70-foot scaffold signals at its terminals in order to establish intervisibility between north and south base. The brick piers, on account of their dimensions and finish, it was found impracticable to carry higher than originally built.

*Height of the base.*—To determine the profile of the base, Assistant Gilbert ran a simultaneous double line of spirit-levels from south to north base, and after the completion of the base measurement the connection with tide water was completed by running similar levels to "bench mark" Hooper, situated 4 miles to the westward on the eastern shore of the Great Salt Lake. The height of this bench mark was determined in 1887 by lines of levels run in opposite directions from the crossing of the Union Pacific and Utah Southern Railways at Ogden, Utah.

The "Hooper" bench is the northern one of a pair of benches established in 1887, by means of which the transcontinental railway levels at Ogden were carried across the waters of the Great Salt Lake to the "Grantville" bench, thence by reciprocal zenith distances to the summit of Deseret peak, the central station of the great quadrilateral which spans the basin of Great Salt Lake. A verification of the height of the base above the ocean, thus found from the railway levels, is assured through the hypsometric work of the transcontinental triangulation which rests upon a very complete and comprehensive series of zenith distances directly connecting with the mean tide water at the Straits of Karquines, California, and the height of Colorado Springs, in Colorado, as derived from the Coast Survey lines of precise levels.

#### MEASUREMENT OF THE BASE.

Having given in the above a brief account of the preliminary preparations, before passing to a description of the measurement of the base, it is deemed expedient for the convenience of the reader to preface it with the following condensed description of the Duplex apparatus:

#### BASE APPARATUS.\*

*The Duplex.*—On the survey the duplex is known as "Base Bars Nos. 15 and 16." It is a bimetallic contact-slide apparatus, consisting of two precisely similar bars wholly constructed of metallic tubing of the smallest dimensions consistent with requisite strength and rigidity. The important characteristics which distinguish it from other forms of bars are: (1) Its two disconnected tubular components; (2) the reversibility of these components; (3) its double metallic

\* For detailed account of the duplex base apparatus, see Appendix No. 11.

truss-tubes, the inner one of which carrying the components is reversible on its axis; (4) the summation, during use, of the minute differences of length of its components and the indication of the sum total of these differences. The components consist respectively of steel and brass tubing of  $\frac{3}{8}$ -inch outer diameter, with walls proportioned in thickness to the specific heat and conductivity of these metals. Their surfaces are nickel-plated in order to insure to them equal power for absorption and emission of heat.

The object of the adoption of the tubular form of construction, and the principle of reversal of the components, is to secure uniformity in the distribution of temperature, or more particularly equality in the mean temperatures of the components, the important requisite upon which the success of every bimetallic scheme unquestionably chiefly depends. Each bar, 5 metres in length, is protected by light jacketing against sudden changes of temperature, and weighs 118 pounds. The flexure of the bars is constant. The components are provided in the usual manner with three mercurial thermometers each. These thermometers mainly serve to convert the apparatus into a thermometric measure. Their bulbs are placed centrally between the components without, however, forming a metallic contact with them.

To facilitate the making of the contacts in either of the reversed or the direct positions of the components, both the upper and nether faces of the contact slides are provided with a set of fiducial lines. The lengths of the components, as defined by these lines, are sensibly the same for both faces. The reversal of the components is equivalent to a change of face.

The relative displacement of the components, and the shifts of "brass" during a measurement, for equalization of their projections, are determined as to amount by the successive readings of the bar-scales. For this purpose each bar is provided with two sets of scales and verniers. The scales are firmly attached to the steel components, and the verniers to the brass components. The scales are 12 centimetres in length, and read directly to tenths of a millimetre. Being symmetrically placed with respect to the agate terminals of the components, the distance between the *zeros* of corresponding scales, or of corresponding verniers, is always the same respectively as the lengths of the steel and brass components. Hence, the differences in the readings of the two rear and the two front scales, diminished by their "*normal readings*," will be equal to the difference in the lengths of the steel and brass components.

The "normal scale reading" is that which obtains when the components have equal lengths, i. e., when at a temperature of approximately  $25^{\circ}.5$  C. This normal scale reading, 40.075 centimetres, may be regarded as an auxiliary constant of the duplex, by means of which the accumulated scale differences may be corrected, if necessary, for one or two extra bar lengths.

A further advantage of the duplex consists in the independence of its principal constants, namely, the standard lengths of its steel and brass components, the thermometric coefficients of expansions of these components, and the so-called differential bimetallic or "duplex coefficient."

This latter coefficient being dependent solely on the *ratio of the expansions* of brass and steel, without reference to either temperature or *definite* lengths, is obviously deducible either from adequate measures made in the field or special standardization experiments upon the comparator base. In certain favorable contingencies preference should be given to the determination of this coefficient from suitable *field* measures. In general, therefore, no special series of observations will be requisite for the determination of this important coefficient.

If simultaneously used both as a bimetallic and a thermometric apparatus, the duplex will furnish three practically independent results from a single operation of measure, which must and will agree if the constants referred to are *consistent*. These are the two thermometric results, one each from the steel and brass components, and the duplex or differential expansion measure from both the components conjointly.

In the matter of manipulation in the field the duplex differs from the ordinary monometallic bar in nothing, except that it requires the making of two contacts for every bar laid, i. e., the contacts between its double components in the sense "steel to steel," "brass to brass."

On account of compactness of construction the duplex proved in this first trial to be not only a portable but also a most convenient field measure, not easily deranged in its adjustments. If used only as a duplex without thermometers, the apparatus is simplicity itself. Interruption or irregularity in the progress of measurement in no way affects its results. Manipulated with but ordinary precaution, it is certain to furnish satisfactory results.

*Standardization.*—Before being shipped to the field, in June, 1896, the new bars were standardized under authority of the Office of Standard Weights and Measures, and their principal constants were determined from a series of 32 comparative measures with the Woodward 5-metre standard bar No. 17, in melting ice, upon the 50-metre comparator line recently established in the grounds of the Coast and Geodetic Survey Office in Washington, D. C.\*

Later in the year, after completion of the base measure and the return of the duplex to the office in November, it was again compared with the Woodward standard through 32 similar measures upon the office comparator. This recomparison, undertaken mainly with the view of ascertaining whether the lengths of the bars had sustained change from wear of the agates, was conducted by the writer under instructions from the Superintendent, in strict conformity with the mode of procedure followed in the base measure. Accordingly, the thirty-two comparative measures were made in four groups of eight symmetrically arranged measures each. In each group the eight measures were made with the components alternately in the positions "face up" and "face down," the change of face being effected by a reversal of the components after completion of each forward and backward measure.

On completion of the second group of eight measures, executed as regards position of the faces in the obverse order, the duplex bars were turned end for end and the remaining sixteen measures, arranged in two groups of similar measures, were executed by measuring in the reversed direction. Throughout this restandardization the duplex apparatus was handled with the utmost care, and the components were accurately aligned and, after completion of each forward and backward measure, were systematically reversed. The thermometers and the scales were also carefully read and verified by two observers, and in order to secure the most favorable temperature conditions each of the four groups was executed during the afternoon hours of the day. For standard lengths these experiments were regularly preceded each day by a double measurement of the comparator base with the standard bar No. 17, in melting ice. The minute expansions in the truss tubes, for which no compensation is provided in the construction, were eliminated by executing every return measure backward; that is, without turning the duplex bars end for end.

In order to properly relate the two series of comparative measures between the duplex and the office standard No. 17 through the ground marks which define the terminals of the comparator base, the end microscope-micrometers, before being pointed upon the duplex components, were invariably first referred to these marks by means of the Repsold cut-off cylinder. Such cut-off references were required at every reversal of the components and the microscope-micrometers were pointed directly either upon the well-focused agate knives or centrally between the direct and reflected images of spider lines stretched for the purpose across the plane-faced front agates. The necessary illumination for these micrometric pointings was effected through reflections from the metallic scale of the Repsold cut-off cylinder in horizontal position.

On completion of the restandardization of the duplex, an exhaustive investigation was undertaken to determine the flexure relations of the trestles. It had been noticed while in the field that the *cradle arms* of these trestles were much too slender and flexible to effectually withstand the push or thrust caused by the double contact pressure of the duplex without sensibly yielding to it, and that an investigation of the matter was, therefore, desirable. With this object in view the bars, supported by the trestles in the usual manner, were placed under the comparator microscopes and the flexure of the cradle arms carefully measured for thrusts of various intensities and lengths of arms. The thrusts by weights were applied and measured in both directions. As was to be expected, the results of this novel and somewhat comprehensive series of experiments show: (1) That the flexure at any length of arm is proportional to the intensity of the thrust; (2) that with respect to length of arm above the base of the cradle, the observed flexure proved to be approximately proportional to the square of the length of arm.

Thus it was found, for example, that while the elastic yield at the head of the trestles was always *nil*, at a point three-fifths of the length up the arms of the cradle, i. e., the estimated average height at which the bars were supported in the field, the flexure due to contact pressure was five microns. Supported at the tops of the cradle arms, the flexure from the same pressure proved to be equivalent to twenty microns.

\* See Report Office of Standard Weights and Measures, by Andrew Braid, Assistant, page 2, Coast and Geodetic Survey Report for 1896. The length of this standard bar is very accurately known in terms of the International Prototype Metre No. 21.



For verification the tension of the helix springs of the contact slides was subsequently determined by means of a delicate spring balance. Thus determined, the flexures from contact pressure and the flexures caused by weights were found to agree. The weights applied in these experiments by means of a pulley and cord were one-half, one, and two kilogrammes. It must be conceded that the magnitude of the observed flexures exceeded expectation and that they could not be disregarded. It was made evident, also, that the duplex apparatus, in consequence of its double contact pressure, required supports of greater stability than is afforded by the trestles used—trestles, by the way, which belong to the monometallic subsidiary bars of the Survey, and were never intended for the duplex.

Next, investigations were also made relative to the uncertainty of making contacts and transferring the components to the ground marks. From eighty contacts noted, twenty for each of the four components, it was found that the probable error of estimating a coincidence of the fiducial lines is  $\pm 2^{\mu}8$ . From twenty measures for transferring the agate knives to ground, using the same centimetre scale and sector transit employed in the field, the probable error of a single transference was found to be  $\pm 85$  microns.

These investigations were very materially simplified by the use of the contact screw micrometers with which the components of the duplex apparatus are provided. The division value of these micrometers is directly derivable from ten or more revolutions of the screw heads measured upon the bar scales.\*

These special investigations of the duplex were concluded finally by observations for the determination of the wear of the agate knives from contact friction. That the knife edges had become somewhat blunted was plainly discernible. The average amount of wear as computed from carefully measured widths of the contact *surfaces*, together with angles of the knife edges, was found to be  $8^{\mu}0$ . In other words, assuming the knife edges to have been perfect when issued from the shop, it seemed established that the combined length of the two bars (Nos. 15 and 16) had shortened by about 16 microns during use. Including the standardization experiments 26.3 kilometres had in all been measured with the duplex. In the computation of the corrections for this wear it was assumed that it was proportional to the *area* of contact surface, or, which is the same thing, that the *volume* lost by wear was directly proportional to the number of contacts. Hence, the  $\frac{1}{26.3}$  part of the whole cubical contents lost was worn away during the measurement of each kilometre.

*Adjustments.*—Like other contact-slide measures the duplex requires two principal adjustments: (1) That of the inclination sectors; (2) that of the aligning telescopes.

*The inclination sectors.*—The sector arcs are divided from  $0^{\circ}$  to  $40^{\circ}$  and read to  $10''$  by two diametrically opposite verniers. Properly adjusted, the verniers read exactly  $20^{\circ}$  when the components are horizontal. This adjustment is conveniently made by means of an ordinary wye level placed at a point about 25 metres distant from, and nearly at right angles to, the centre of the bar and at the same elevation. When the bars have thus been placed in a truly horizontal position the sectors, whose verniers have previously been set to the proper reading, are adjusted so that their level bubbles assume a central position. This adjustment should be frequently verified.

*The aligning telescopes.*—The adjustment of the aligning telescopes consists chiefly in making their sight lines parallel to the axis of the reversing tube. In the absence of more convenient means this adjustment may be effected as follows: Select an even and nearly level piece of ground, and after having placed the bars upon the trestles adjust the aligning telescopes for collimation; next, with the aid of the sector transit, range out, in a straight and approximately level line on the ground or upon posts, three nails, viz, one near each end of the apparatus and the third about 75 metres distant ahead upon a fence post or other convenient object; next, stretch a cord between the two near nails, which cord, if proper care has been taken, will be accurately in the line fixed by the three nails; next, having set the knives and rollers of the trestles level and to proper elevation, shift the axes of the bars accurately into the vertical plane through the stretched cord by means of suitable plummets; next, set the axes of the aligning telescopes horizontal and,

\* The heads of these micrometers are divided into twenty-five divisions. From a series of measures of full turns upon the bar scales the value of one division was found  $= 25^{\mu}4$ .

without disturbing anything, adjust them in azimuth until they bisect the distant nail. This, if properly done, completes the adjustment, and will insure parallelism between the sight lines of the aligning telescopes and the axes of rotation of the reversing tubes. The lathe centres in the headpieces of the truss tubes will serve the purpose of placing the bars in the vertical plane through the stretched cord. Although it was found that this adjustment, as well as that of the inclination sectors, proved to be uncommonly permanent during the Salt Lake base measure, they were, nevertheless, tested a number of times and kept under control by the range afforded by the line flags at the section posts. It should also be remarked that inasmuch as the plane of collimation of the telescopes falls centrally between the two parallel components, in order to keep either one of them in the line of measure it is necessary to point the aligning telescope a little out of the centre. In the base measure, steel, when "face up," was kept in the line of measure, which was accomplished by directing the pointings five-eighths inch to the right of centres of the line flag poles.\*

*Sector transit.*—The sector transit used in referring the components to the ground marks was always set up on the left side of the line, looking in the direction of the measurement. This required the centimetre scales to be placed so as to read in the direction of the measure, which is desirable.

The sector transit was, of course, always placed normal to the end of the bar to be referred, approximately 30 feet distant from it, and, to insure equal definition, at about half the elevation of the bar above the ground. This latter condition was accomplished by means of a short-legged tripod provided for the purpose. The adjustments for collimation and horizontality and verticality of the axes of the sector were accurately made and controlled throughout the measurement. The pointings upon the agates of the components and the centimetre scales were always twice made, i. e., once in the direct and once in the reversed position of the transit.

The normal direction of the transit was determined in the following simple manner: A parallel ruler,  $2\frac{1}{2}$  inches in width and about 10 inches in length, was placed flat upon the projecting components and gently pressed against the end face of the truss tubes. Tilting the ruler slightly downward and sighting along its outer edge, the center of the sector tripod was ranged into this line and set up at the desired distance. It should be remarked that inasmuch as the headpieces of the truss tubes were fitted by lathe work, their faces are necessarily normal to the axis of the truss tubes. Pointed upon with the sectors placed as above explained, reversals of the components, when set to normal position by the mirror, brought out no perceptible discrepancies. This method of placing the sector transit at a normal direction, which is peculiar only to the duplex, was found to be so convenient and expeditious that it was exclusively employed as soon as recognized.

*"Set-ups" and "set-backs."*—In referring the agates of the components to the ground marks, a "set-up" is a quantity additive to, and a "set-back" a quantity subtractive from, the measure obtained by means of the base apparatus. The shifts of brass upon steel for the purpose of equalizing the ends of the components belong to the same category. They affect the measure from brass in either the additive or the subtractive way, according as the readings of the scales are thereby increased or decreased.

The "set-ups" and "set-backs" were measured by means of 10-centimetre scale, Coast and Geodetic Survey, No. 190, the graduations of which on investigation by the Office had been found to be free from appreciable error.

Placed horizontally upon the section bolts and parallel to the line of measure, the scale faces the sector transit and the graduations increase in the direction of the measurement. This latter circumstance proved an excellent safeguard against confusion or mistakes in noting the "set-ups" and "set-backs," which were made with the utmost care and were verified in every instance to obviate possible mistakes.

*Scales and scale readings.*—As before explained, the scales of the duplex are centimetre scales, firmly attached to the steel components, whereas the verniers, which are adjustable, are secured to and carried by the brass components. These scales, etc., of which each bar has two sets, are graduated to millimetres and read directly to tenths. The hundredths are determinable by estimation. The scales are 12 centimetres in length, and to avoid confusion in the readings are differently numbered. Thus, for example, when the rear scale of bar No. 15 reads

\* If the sector transit be always set accurately normal to the line of measure, which is easily done in the case of the duplex, it will be simpler and preferable to keep the centres or axes of the bars in the line of measure.

5 centimetres the rear scale of bar No. 16 reads 45 centimetres, etc. The graduation of the scales increases from rear toward front, or, which is the same thing, in the direction of the measurement. Hence, if during measurement "brass" advances upon the "steel" the scale readings increase; if "brass" recedes the scale readings decrease. Brass obviously will  $\left\{ \begin{array}{l} \text{advance} \\ \text{recede} \end{array} \right\}$  upon steel so long as it is  $\left\{ \begin{array}{l} \text{longer} \\ \text{shorter} \end{array} \right\}$  than steel.

The difference in the scale readings of successive bars, diminished by the normal difference, is equivalent to the difference in the lengths of the steel and brass components. The lengths of the two bars 15 and 16 are sensibly equal, viz, 5 metres each.

For the reduction of the scale differences from 99 to 100 bars, or from 1 to 2 bars, as the case may be, a knowledge of the *normal* difference in scale readings is required. This auxiliary constant is determinable in various ways, as, for example, from the scale readings when the brass and steel components are of equal length. The components of the two bars (15 + 16) have equal length when at the mean temperature  $+ 25^{\circ} \cdot 5$  C., as indicated by the mercurial thermometers.

The normal differences in the scale readings depend upon the adjustment of the verniers. This adjustment may be made very secure and practically invariable. As at present adjusted these differential readings are for the rear scales  $R\ 16 - R\ 15 = 40 \cdot 04$  centimetres and for the front scales  $F\ 16 - F\ 15 = 40 \cdot 11$  centimetres.\*

*The plane mirror.*—For the convenient and expeditious reference of the components to the ground marks, it is essential that they project normally from the truss tubes. A simple means by which they may be made normal is an ordinary plane mirror. If held in a vertical position and gently pressed against the agates of the components their ends will obviously be normal to each other when they, and their reflected images, appear in straight lines, i. e., as prolongations of each other. Therefore, if upon trial it be found that they appear at an angle, shift "brass" (never "steel"), by means of the contact screw, until they do appear straight, which may be accurately judged, in the absence of special provision, by the projecting stems of the thermometers. The entire reliability of this process was abundantly tested and established by pointings with the sector transit, at a normal position, and reversals of the components. Reflections repeated after reversal of the components also afford an accurate check.

*The trestles.*—The wooden trestles which were used in the Salt Lake base measure belong to subsidiary monometallic bars, Coast and Geodetic Survey, Nos. 13 and 14. The foot plates, provided to give greater stability to the trestles when crossing soft or yielding ground, were not used, as the ground along the Salt Lake base site, being thoroughly sunbaked, afforded all needful stability without them.

The setting of a continuous series of trestles is a task beset by many trials and difficulties, requiring close and unremitting attention to secure the proper conditions of alignment, distance, grade, and stability, all of which are essential and requisite, and must always be promptly and satisfactorily secured if neither speed nor the accuracy of the measure is to be sacrificed.

The line of the trestles is maintained by the range of the bars themselves; their distance or position is fixed by measures, not from the last trestle set but from the black bands around the bars.

In order to insure at once the most advantageous gradients compatible with the profile of the site, clamp the cradle bars at an elevation such that their bearing edges coincide with or touch the horizontal line defined (or fixed) by sighting tangent to the roller or knife edges of the preceding trestles and the distant horizon line in the direction of the base. In other words, set each successive trestle to an average uniform gradient irrespective of the incidental inclination of the preceding bar. For, so set, the bars on being placed upon them will also be parallel to the ground and in position ready for approximate contact.

The rapid and stable setting of the trestles was greatly facilitated by providing each trestle leg with a cleat, bolted to it just above the iron ferrule at its foot.

To adjust, bring the cradle bearings to a horizontal position by means of a carpenter's level,

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\* The effect of reversal of the components upon the mean scale readings is but trifling and may usually be disregarded. From a series of readings made for the purpose the discrepancy was found to be for bar 15, "face-up,"—"face-down," =  $+ 0 \cdot 0024$  millimetres, and for bar 16, "face-up,"—"face-down," =  $- 0 \cdot 0084$  millimetres.

or similar instrument, clamp securely, and, with a screwdriver, loosen one end of the block carrying the embedded level, bring the bubble to the center, and tighten screw. Reverse and correct to true center.

When arranged in a line and set horizontal with the small spirit levels embedded in cradle bars, the top edges of the knives and rollers should be parallel. Test this by glancing over the tops of them. If on so doing it appears that one or more of the rollers or knives are materially out of parallelism, correct them by approximately raising (or lowering) the particular bars, and then adjust the levels accordingly. Although it is desirable, when set by means of these levels, that the cradle bearings be horizontal, it is not essential that they be accurately so. It will suffice if they are parallel among themselves. Also oil all screw bolts so as to clamp easily, and firmly secure the cradle arms by tightening the screws underneath the head pieces of the trestles, etc.

*Field Procedure.*—On the morning of the third day of September, after a careful adjustment of the inclination sectors and the aligning telescopes, at camp, the duplex was hauled to North Base on the laps of six men appropriately seated in an ordinary freight wagon, and the first measurement of the base began there in the afternoon.

The entire measurement of the base was carried out with the bars supported and maintained in position by the ordinary field trestles above described.

For the protection of the apparatus and party during the measurement, a light canvas-covered sled, a movable structure traveling on runners, was provided.\*

The base line was measured twice, once in each direction. It was divided into eleven sections, each a kilometre in length, excepting the eleventh, which has a length of 1.2 kilometres. Each section, therefore, contained an even number of bar lengths. They are consecutively numbered from I to XI.

To obviate the inconvenience of referring the measuring bars to the permanent end marks of the base inclosed in the hollow brick piers, two posts 5 inches in diameter and 3 feet long were placed in the line of the base, just outside of the piers, or approximately 0.8 metre distant from the permanent surface monuments. The exact line points were marked by copper bolts provided with fine cross lines. These subsections, designated "A" and "B," were directly measured with a 3 meter fractional bar, once at the start and again at the finish, respectively, of the first and second measurement of the base with the apparatus.

The *modus operandi* pursued in the measurement was the following: The trestles having been previously arranged in appropriate position and securely clamped, the first bar (No. 16 in this instance) was placed upon them, and accurately aligned in such a manner that the steel component fell in the line of measure, its rear end approximately vertical over the ground mark at "B." Next, a transit sector was placed to the eastward of "B," about thirty feet distant and at right angles to the line of measure, and the agate knife-edge of "steel," set to fiducial zero, plumbed down in the usual manner by noting the scale readings for both the knife-edge and the ground mark; next, the bar scales and the mercurial thermometers were read, the latter quickly lifted from their seats, and the components reversed. This reversal brought the brass component into the line of measure. On setting the contact slide of "brass" to coincidence of its fiducial lines, its knife was immediately referred to "ground" in precisely the same manner as was the steel component. Next, the scales and the thermometers were provisionally read, the latter removed, and the components reversed back. This restored the bar to its direct or first position, and a final reading of the inclination sectors, the scales, and the thermometers, completed the laying of the first duplex bar in the Salt Lake base measure.

Next, the trestles having been arranged and set to grade beforehand, the second bar, 15 in this instance, was placed in approximate alignment and its rear end adjusted to proper height by means of the wedges, and the trestles firmly clamped. Next an approximate contact was effected by a backward sliding of the whole bar upon the trestles and the final alignment of its forward end by lateral shifting and telescope pointings upon the line flags ahead. Next, the contacts between the components, "steel to steel" and "brass to brass," were made perfect by means of the contact screws, and the laying of this second bar was completed by noting the readings of its

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\* For detailed description and illustrations see further on.

scales, thermometers, and its inclination sectors. Next, on command "ready launch," the first rear bar (16) was withdrawn, carried forward by two men, and, under guidance of the proper officers,\* was placed upon the next pair of trestles and approximately aligned. Next, after having accurately adjusted its rear end for height by the wedges of the cradle, the bar was again bodily slid backward into approximate contact, which, after final alignment by telescope pointings, was properly perfected in the usual way by means of the contact screws. The readings of the inclination sector and the thermometers, simultaneously with making the final contacts, completed the laying of the third bar. Next, at command as before, the second bar (15) was launched, carried forward and placed upon the trestles, etc., as before explained. At the same time the shelter sled was drawn forward a bar's length by a pair of horses, in order to keep the apparatus and party well sheltered from the burning sun.

Inasmuch as during this first measurement the duplex was on trial for general efficiency as a composite apparatus, neither care nor precaution were spared to insure precision in the execution of every detail essential to the operation. Thus the thermometers of the bars were regularly read as soon as each was successively laid. The scale readings, however, as being of no further importance, were discontinued after the laying of the second bar.

At the beginning of a measurement the scale readings of the first two bars laid, together with the "set-up" or "set-back" measures for the brass and steel components at the starting point, are all that is required in addition to their temperatures and inclinations, for the three independent results it was the aim to secure in this measurement.

The general plan of measurement which was methodically pursued in the base measure is illustrated in the following diagram of a kilometre section:†

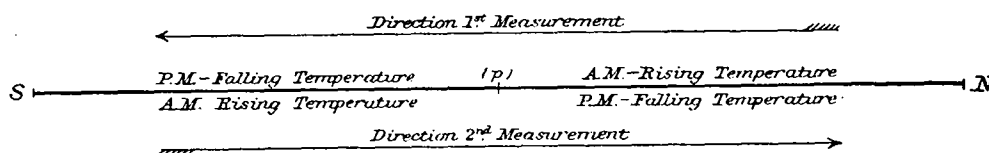


Fig. 2

Each kilometre section, it will be seen, was measured twice, once forward and once backward, as before explained. Each measurement was executed in a day, during particular hours in the morning and evening. The half-kilometre points were introduced into the measure for the exclusive purpose of testing the new apparatus for thermal behavior. Being at the middle of each section, they also served conveniently for the midday stops. The daily measures were regularly referred to these points, and caused no extra work or delay whatever in the adopted routine duty of the work.

For testing the behavior of base apparatus under field conditions, the series of half-kilometre measures, arranged and executed as shown, affords peculiar advantages, chiefly on account of reversal of the second measure in direction, that each half section is thus measured once in the morning under rising temperatures and again in the afternoon under falling temperatures, or vice versa, as the case may be, while the whole sections are measured under as similar temperature conditions as obtain during the same hours of the two different days.

This was the plan of measurement followed and the object sought. Unquestionably the plan is thorough, and if methodically pursued under favorable weather conditions is bound to bring to light the thermic faults of a bar, however insignificant they may be.

The difference in the measures thus obtained under favorable weather conditions will be nil

\* The officer making the contacts in the meantime remained at his place or position, in order to protect the rear trestle and bar from being struck or accidentally disturbed in any way by the men while carrying the bar and trestles forward.

† This method of conducting the measurements of base lines was proposed by me in 1885, as part of the duplex scheme, for the express purpose of testing the thermal efficiency of base apparatuses. Only very recently I have noticed that the remeasurement of the "Bonner Base" in 1892 was executed after the same general plan. See "Die Neumessung der Grundlinien, etc.," by the Prussian Geodetic Institute, Berlin, 1897.

for the whole (daily) sections, no matter what the character of the apparatus, whereas for the half sections they will be of appreciable magnitude and of a systematic nature, i. e., their algebraic signs will regularly alternate, unless the apparatus used chanced to be thermically perfect, in which case the differences in question would obviously also be zero. Hence, the differences in the measures for the half sections, if appreciable and alternating in their signs, will be systematic in character, and on that account will be mainly significant in so far as they exhibit or serve to determine the thermal characteristics of the apparatus employed; for example, in the case of the duplex, whether it be equally efficient as a bimetallic and as a thermometric apparatus. On the other hand, the *daily* results from the *whole* sections can contribute nothing toward a satisfactory solution as regards the question of either the thermal perfection of the apparatus or the reliability of the results in "*normal*" measure.

*The movable shelter.*—This valuable adjunct, which was used in the base measure for the protection of both the party and the apparatus, consisted, as before stated, of a large canvas-covered sled traveling on runners. It was a "double-ender," 56 feet in length, 12 feet in width, and 9 feet in height at the ridge line of its arched roof. Framed out of Oregon fir of the lightest permissible dimensions, it was bolted together into a rectangular-shaped open truss in such a manner as to convert its posts and diagonals, respectively, into ties and struts. By this means the framework of the truss was sufficiently strengthened to retain its shape, no matter whether supported at the middle, as when crossing a dike or embankment, or at the two ends, as when crossing a broad ditch or sharp depression in the ground. During the measurement this sled was drawn along over the undisturbed natural ground by two horses. Weighing not over 3,000 pounds, it glided easily over ditch, furrow, or railway embankment, answering its purpose admirably. It occasioned no delays, and as for simplicity, convenience, and cheapness it would be difficult to construct a movable shelter more effective or complete. The cost of the material used in its construction, as lumber, carriage bolts, nails, and canvas covering, did not exceed \$65.

During measurement the two ends of the sled were always kept open. The side curtains were usually so regulated by reefing as to prevent the sun's rays from striking the apparatus, but not to interfere with the free circulation of the air. During hours when the wind was too strong the side curtains were lowered enough to prevent it from striking the apparatus. In short, the sled afforded every desirable protection against the burning heat of the desert, etc., and so enabled the party to pursue the measurement of the base uninterruptedly at all times. Only on one occasion, during very high wind, did it become necessary to discontinue the work on account of the danger of overturning the sled.

Its utility and beneficent effects, not only upon the results of measure but upon the health and temper of the party, can not be easily overestimated. It is much to be doubted whether without the comforts and protection which this sled afforded the party would have been able to measure nineteen kilometre sections in nineteen consecutive working days, as it actually did. Not less than two days' time were saved on account of rainy weather. It more than saved its cost in time alone. The advantages that are secured through the employment of such a sled are so many and so pronounced that no important base measurement should be executed without a similar movable shelter.

The first measurement of the Salt Lake base was brought to a finish on the 17th day of September. The return measurement was started next day and concluded on the 3d of October.

*General summary.*—In the beginning of the measurements the transferences of the rear ends of the bars were effected by clamping the contact slides of the components to the fiducial zeros. Each component was independently referred to "ground," i. e., without prior attempt at equalization of their projections from the truss tubes by means of the mirror. The sector transit was always set up on the left, looking in the direction of the measure, normal to the end of the bar and about 30 feet distant from it. The pointings upon the agates of the components were always made double, i. e., once with the transit in the direct and once in the reversed positions, each accurately leveled. The graduations of the scales, placed always so as to increase in the direction of the measure, served admirably to prevent confusion in the "set-up" and "set-back" measures.

Except for the "set-ups" and "set-backs," the measures of the sections from "steel" are continuous. The equalization of the projecting components was effected, whenever necessary, by

shifting of "brass." "Steel" was never changed. The measures from the brass components are therefore not continuous, but require correction for "shifts." As to amount, these "shifts" are equal, of course, to the differences of the accompanying scale readings. To obviate as much as was practicable the "shifts" occasioned by excessive relative displacement, "brass" was always set ahead or back of "steel" one-half the quantity it was likely to lose or gain on "steel" in any contemplated measure. Close attention to this useful expedient resulted largely, if not wholly, in the prevention of the "shifts," excepting the few measures that were made during the extremes of the temperatures of the field season, where it was unavoidable. The extra "shifts" required in the Salt Lake base measure were but few.

Throughout the measurement of the base the steel and brass components were independently referred to the section posts. This was judged desirable in order to render the individual results from steel and brass as independent as possible. Ordinarily the reference of steel alone suffices.

A preliminary measurement of the northern fraction of section XI was made with the view of affording the operatives of the party an opportunity to familiarize themselves with their respective duties, and to gain practice in the manipulation of the new apparatus. Naturally during this first attempt at measuring with the new apparatus progress was slow. The party lacked training and familiarity with the working of the mechanical details of the bars, and the mode of the field procedure had not yet been sufficiently developed and systematized. This practice measurement was not used in determining the final length of the base.

Though during nights the thermometers were taken from their sockets and securely packed away in a box lined with cotton batting, the bars themselves were left on the trestles in order to keep them out of the chilly or frosty air that usually collects upon the flat lands about the Great Salt Lake during the early morning hours in quiet bright weather.

For the better protection of the apparatus during nights, before quitting the field of work the canvas curtains of the shelter sled were dropped and tied to the runners, and the sled well secured to the ground by stakes and guys. The watchman who was left in charge was permitted to swing his hammock and live within the sled thus closed down.

Each morning, after having replaced the mercurial thermometers in their regular order and tested the adjustments of the inclination sectors, the measurement was resumed by accurately aligning bar 16, the first bar of the contemplated measure, and by placing the knife-edge of its steel component, set to fiducial zero, in the vertical line passing through the "night stone," and then proceeding in the same manner as before described.

In order to preserve regularity in the methods of execution, the measurements of the half sections were invariably begun with the components in position "face up," i.e., "steel" in the line of measure.

The principle of reversal of the duplex components was regularly observed by turning the components once at the middle point of each measure or at the quarter-section points.

Though the uniform practice in the Salt Lake base measure was to always read the bar scales in connection with the reversals, it is, nevertheless, obvious that it was entirely unnecessary to do so, for on account of construction and precision in workmanship, reversals of the components in nowise affect the continuity of their measures.

Simultaneously with these reversals occasion was taken, whenever required on account of the temperature of the day, to equalize the projecting components by shifting "brass" by means of the contact screws. The magnitudes of these shifts were determined by a special set of scale readings.

On completion of the measurement of the third kilometre, sufficient training and experience in the handling of the new apparatus had been acquired by the party to easily measure at the rate of 40 bars an hour, or a kilometre section in five hours. Moreover, as the real needs of the new apparatus, calculated to insure dispatch and accuracy, were being better understood, some modifications in the methods of procedure were introduced. For example, in order to strictly conform to the adopted plan of measurement, and to save the time and labor required to establish temporary line points, the first half of every kilometre section was completely measured in the morning and the second half in the afternoon of each day. A further modification which was adopted consisted in regularly equalizing the ends of the components of the first and last bars

of the half-kilometre measures by the mirror before attempting their transference to the ground marks. This, it will be seen, saved the independent reference of the brass component to "ground;" that is to say, on finishing the measure of a half section, "brass" was shifted forward or backward until normal with front of "steel." Reference of either "steel" or "brass" to ground was then made in the usual manner. For a check, the components were occasionally reversed and "steel" tested by transit pointings. But it should be remarked in this connection that on account of reversal of the components midway of the half-kilometre measures they are always in the reverse position at its end, i. e., "face down," and "brass" in the line of measure.

On resuming the measurement after the noon rest or in the morning, the components having previously been turned to the position "face up" and "steel" placed in the line of measure, the front end of "steel" of bar 15, the last bar of the preceding measure,\* was always placed vertically over "ground" by means of the contact screw micrometer. To this end "ground" was picked up by transit pointings and "steel" brought into contact with vertical spider lines by means of the contact screw. A satisfactory contact having thus been effected, the reading of the contact screw micrometer was noted. Next the transit was reversed, leveled, and "ground" again picked up and brought to the height of "steel." If this second pointing proved imperfect, as was usually the case, on account of axis inclination, "steel" was again moved by the contact screw until in apparent tangency with the spider line of the transit and the micrometer reading noted the second-time. Next the micrometer was set to the mean reading and "steel" assumed to be truly vertical over "ground." Next, by application of the plane mirror pressed gently against "steel," "brass" was shifted forward or backward until the direct and reflected images of the bar seemed in the straight line, and the front agates of the components were then assumed to be normal to the axis of the bar. The knife agates of bar No. 16, the *first* bar of the proposed *new* measure, were then brought into contact in the usual way with "*front*" of bar No. 15, placed as above explained, and the clamping of the contact slides to zero and the separate plumbing of "brass" to "ground" were thus obviated. In this first position bar No. 15 merely served to start the measure. The scale readings required at this juncture are those of the next two bars, i. e., Nos. 16 and 15, or the first two bars of the new measure.

With regard to ascertaining the total "shift" of "brass" for each half or whole section, i. e., for each 100 or 200 bars, from the scale readings direct and without necessity of reduction, it is suggested to carry the measure of each half section one bar beyond the section posts, or, better still, to read the scales of bar No. 15 after having been placed in position as just above explained for the beginning of a new measurement, as it will save the time of laying the extra bar.

These expedients were practiced in the Salt Lake base measure with much success. Should either of these prove at any time impracticable, as is not unlikely, then the relative total shift of "brass" upon "steel," as derived from the first and last scale readings for every  $100-1=99$  bars, may be reduced to 100 bars by applying as a correction the difference between the actual scale readings of the last two bars laid and the corresponding "*normal difference*," namely, 40.075 centimeters, as before explained.

In order to insure ease and freedom in the longitudinal sliding of the bars, the "creases" in the rear bearing plates of the bars and the knife edges of the rear trestle were removed. The friction due to the great weight of the bars insures to them ample stability against slip on account of inclination without the former. As before stated, there is nothing in the whole operation which promotes speed of measurement so effectively as does rapidity in establishing the preliminary contact by the sliding of the bars bodily upon the trestles.

During progress of the base measurement the shelter sled, drawn by a pair of horses, was regularly hauled forward simultaneously with the launching of the rear bar, and while it and its trestles were being carried forward by the men. After a few days of training the sled moved along with remarkable precision and steadiness, starting at the instant of launching the rear bar, and stopping usually within a foot of the desired position at the ringing of a bell.

\* In the Salt Lake base the measurement of each whole or half section commenced with bar No. 16 and finished with No. 15. The setting of the blunt front ends of the components normal to one another by means of the mirror is a matter much more readily accomplished than the setting of the contract slides to fiducial zero. In fact, this method was found to be so convenient, accurate, and expeditious that its adoption and practice in connection with the duplex is recommended.



The distribution of the operatives who participated in the Salt Lake base measure, together with the positions of the trestles and the bars under the sled during measurement, is shown in Plate No. 3. The sled, as before stated, proved a most admirable and valuable adjunct in the base measurement. On account of the numerous furrows and water ditches which crossed the base line, a shelter mounted on wheels could not have answered nearly as well.

The organization of the party, as given under the head of "Personnel of the party," exactly suited the needs of effective and uninterrupted handling of the duplex in the progress of the base measure. After thorough training its movements were characterized by a swing and precision of action more complete and more rhythmical than were perhaps ever before attained, certainly never excelled, by a base-measuring party. To fully appreciate this it must be borne in mind that the party broke all previous records by carrying the measure forward (by means of the ordinary field trestles) at the unprecedented rate of 70 bars per hour.

As of interest also, in conveying a clear conception of the magnitude of the work accomplished in the Salt Lake base measure, it may be remarked that 9,400 trestles were set on the natural ground and 4,700 bars laid.

The trestles used certainly possess considerable range of adaptability to peculiarities of the ground, but the cradle arms were found to be too weak and flexible for the double contact pressure of the duplex, notwithstanding they were always thoroughly clamped.

The setting of the trestles during an accurate and rapidly progressing measurement is a matter of much consequence. There is considerable knack, good judgment, and unbounded perseverance associated with it. To set a series of trestles at once to a uniform grade and with the needful stability is a task, if well performed, worthy of the highest recognition and acknowledgment.

In setting these 9,400 trestles of the base measure a creditable work was done. Judged by the grade corrections, which do not average as much as 3 centimetres per kilometre, it is very much to be questioned whether a better or more uniform series were ever before set than the series of 9,400 trestles of the Salt Lake base measure; in view of which it seems but fair to state that this creditable performance is due to the perseverance, the skill, and good judgment of Assistant H. P. Ritter of the Survey, and C. S. Wilkes, a civil engineer acting as foreman of the party.

The range of free motion in the contact slides, about 8 millimetres, practically renders the making of the approximate contacts largely a matter of chance. That is to say, on placing a new bar by sliding it bodily it is as likely that it will be laid too close as not close enough to the preceding one in position. The secret of rapid measurement—that is, the knack by which perfect contact is most readily effected—was found to consist in first establishing an approximate contact between the consecutive bars by sliding the bars bodily upon the trestles (partially relieved of their full bearing upon the rear trestles in order to diminish friction), after which "final contact" is quickly effected by a turn or two of the contact screws. But the utmost care must be exercised in thus bringing about the approximate contact to shield the agate knives against injury, which is perhaps most easily effected by pushing the contact slides back and placing the forefinger of the left hand in front of them. A sudden lurch or slip of the bar, should it inadvertently occur, may thus result in a "gentle squeeze" of the finger, but it will protect and save the agates from injury.

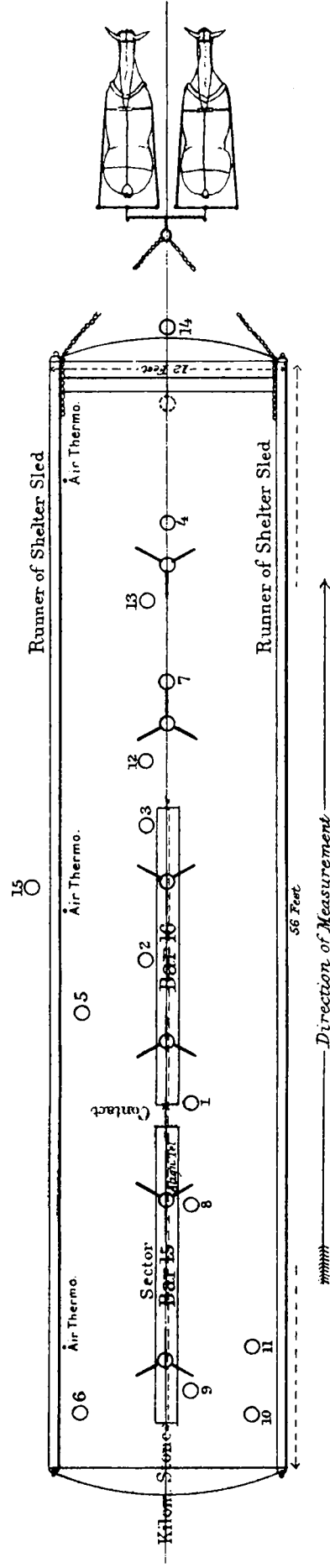
In the base measure this expedient was steadily practiced, and after some little experience had been gained final contact between the bars was established with surprising rapidity. It became quite evident, in fact, that the time required for bringing a bar into position is expended not in effecting precision of contact but in aligning the bars and adjusting their rear ends to proper height. To perfect the coincidence in the fiducial lines by means of the contact screws is, as a rule, a matter of but a few moments. The necessity of having to make two contacts for every bar placed thus proved to be neither an inconvenience nor a drawback as regarded the speed of measure with the duplex.

For the purpose of studying the behavior of the duplex with reference to the fluctuations of the temperatures of the air, three thermometers were regularly read every half hour during the measurement. For protection against radiant heat, etc., these were suspended on the shady

# The Salt Lake Base Measure, Utah, 1896

Diagram showing the Disposition of the Party and the Apparatus, during

Measurement, under the Shelter Sled



## Personnel of the Party

- |   |  |
|---|--|
| No. 1 Einbeck, Contacts.                  | No. 8 Hand, Launching and carrying the Bars forward      |
| " 2 Gilbert, Incl. Sectors & Thermos.     | " 9 " " " "  |
| " 3 Welker, Aligning, Thermos; Scales.    | " 10 " " " "   |
| " 4 Ritter, Spacing & Aligning Trestles.  | " 11 " " " "   |
| " 5 Yates, Recorder & Records.            | " 12 " " " "   |
| " 6 Lynch, Air Thermos & Comdador of Sled | " 13 " " " "   |
| " 7 Wilkes, Foreman & Rear Trestles.      | " 14 Driver of the Shelter Sled.                         |
|   | " 15 Hand, setting aligning flags & opening wire Fences. |

The Rear Bar was launched, the Trestles picked up and all carried forward simultaneously with starting up the Sled and moving it forward 5 Metres.

side, within the shelter sled, about  $6\frac{1}{2}$  feet above the ground. A comparative examination of these temperatures demonstrated that the bar temperatures followed the fluctuations of the air temperatures very closely, seldom deviating therefrom by more than a couple of degrees, even during periods of rapid change. Thus the differences in the *mean* temperatures of the air and apparatus for each one of the two measurements of the base, for example, did not exceed  $0^{\circ}.4$  C., the mean air temperature being the lower in both cases.

Since the reversal of the components requires the temporary removal of the thermometers from the bars, in order to prevent material change in their indications from exposure to the open air between times, the reversals were usually executed with dispatch and the thermometers immediately restored to their respective sockets.

The entire reliability of every observation—as the shifts of the brass components, scale readings, or “set-up” measure, etc.—which in any way entered into or affected the base measurement, was the subject of constant concern, and was accomplished, it is believed, through persistent watchfulness and independent verification, as far as necessary, by different observers. Nothing, in short, was left undone that in any manner seemed calculated to contribute to the completeness and the accuracy of the measurement or the record thereof. The relative shifts of the brass components, affecting as they do the continuity of the measure, were noted and controlled with especial care.

Inasmuch as a speed of 40 bars an hour easily admits of measuring a kilometre section in five hours, the time for daily measurement may be so chosen as to insure, in general, both rising and falling temperatures every day. In the Salt Lake base the daily measurements were therefore taken up as a rule at 10.30 in the morning and concluded at about 5 o'clock in the afternoon. By reducing the midday stop for rest to an hour, from 2 until 3 o'clock, the resumption of the measurement in the morning may safely be deferred until 11.30 and the afternoon measures may be continued until 5.30. There can be no question that the practicability of so timing and conducting the operations in the field as to insure measures for each of the half sections of the base under falling as well as rising temperatures has been fully established.

It may finally be remarked that measuring bars, whether thermically perfect or imperfect, will each give results entirely consistent in themselves, whether used under constant or variable temperature conditions, provided the latter be not too dissimilar. A mere agreement of the results of measure is therefore not to be accepted as positive proof of their reliability. In all such cases the question as to the *normal lengths* of a measure, or of the *thermal efficiency* of the apparatus, is liable to remain wholly obscure and indeterminate. In other words, the precision as well as the reliability of the results of measure, and the thermal perfection of the bar with which obtained, is satisfactorily determinable only by a mode of measuring either the same as or similar to that followed in the Salt Lake base measure.

Measuring a base line to an equal extent under rising and falling temperatures without regard to any such particular plan or method, while it will probably yield a true length for a *whole* base, can furnish no data from which the precision of the resulting measure may be with certainty inferred.

As the practical outcome of or the experience gained in the Salt Lake base measure, it may be safely asserted that, assuming a settled mode of field procedure and ordinary familiarity with the principles of its construction and action, the duplex will be found so simple and reliable an apparatus that if manipulated with but ordinary care its employment is bound to insure results of exceptional precision and reliability.

Referring now to the provisional results of this carefully measured base line, as given below, it will be seen that, in so far as their agreement seems qualified to bear out the preceding observations or to establish the thermic characteristics of the duplex apparatus, they leave no question as to its uncommon perfection both as a bimetallic and thermometric apparatus. The small differences in the measures for half sections, although not yet fully reduced and investigated, prove this beyond a reasonable doubt.

As computed from the results for the whole sections, both from the duplex and thermometric measures, the average relative precision attained is 1-5,000,000th part, which is as great as that obtainable by the Woodward 5-metre bar No. 17 in melting ice, and greater than that yet attained by any other field apparatus hitherto constructed and tried, either in this country or abroad.

Although the cost of measuring with the duplex can not be definitely estimated, being as a rule largely contingent on circumstances beyond control, it will nevertheless be useful to indicate that, owing to simplicity of its construction, portability, ease, and rapidity of manipulation, it can neither be essentially greater nor less than the cost of measuring with the monometallic apparatus of the Survey or metallic tapes and thermometers. Thus, for example, in the present case, in which, as we have seen, fully 23 kilometres were measured in twenty-three working days, i. e., within thirty days, inclusive of Sundays and days lost on account of unfavorable weather, etc., the total cost of the measurement of the base, including preparations, signals, marking, etc., but excluding pay and transportation of the five regular Coast Survey officers, was at the rate of about \$100 per kilometre, single measure.

The personnel of the base-measuring party included the following officers:

William Eimbeck, Assistant and chief of party. Contacts between the duplex components and scale readings.

J. J. Gilbert, Assistant, rear bar alignments, inclination sectors, thermometers, transferences, and field computations;

P. A. Welker, Assistant, front bar alignments, thermometers, sector transit, inclination sectors, and verification of bar scales;

H. P. Ritter, Assistant, front trestles and transference of the bars to the ground marks;

Charles C. Yates, Assistant, keeper of the records and assisting in the field computations;

Buford Lynch, air thermometers and miscellaneous;

C. S. Wilkes, civil engineer, rear trestles and adjustment of the inclination sectors;

Certainly, in view of the exceptional success achieved in the Salt Lake base measure, etc., credit is due to these gentlemen for their able and untiring support.

In the restandardization of the duplex at Washington, I had the valuable assistance of the following officers, namely:

P. A. Welker, W. I. Vinal, G. R. Putnam, R. L. Faris, and Chas. C. Yates, Assistants, and L. A. Fischer, Adjuster of the office of Standard Weights and Measures, and E. G. Fischer, Chief Mechanician of the Coast and Geodetic Survey.

The shelter sled referred to on page 765 was constructed by Assistant J. J. Gilbert in conformity with general suggestions made by the writer. The substitution of the ordinary sled runners for wheels, such as were used on the Yolo shelter carriage, proved in every way a success. The actual execution of the measurement of the base under the protection of this sled required fifteen persons.

The practicability of constructing equally efficient measuring bars, in conformity with either the thermometric or the bimetallic type, seems fully demonstrated by the remarkable accordance of the results obtained in this measurement. Moreover, if it be borne in mind that the Duplex yields from every single measurement *three* separate results, whose degree of concordance establishes not only their entire trustworthiness but throws also much light upon the thermal behavior of the apparatus and the care with which it was manipulated during the measurement, it would seem to be warranted to assign to it first place among the accepted base apparatus of the day. No other bars hitherto used in geodetic work can lay claim, in my judgment, to so unique and practically significant a distinction.